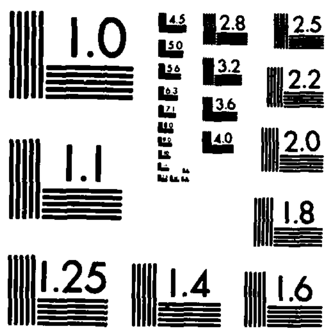
AD-A120 402   ATTENTION CONTROL IN COMPLEX INFORMATION PROCESSING   1/1
TASKS(U) TECHNION - ISRAEL INST OF TECH HAIFA CENTER OF
HUMAN ENGINEER.. D GOPHER ET AL. JUL 82 HEIS-82-7

UNCLASSIFIED   AFOSR-TR-82-0845 AFOSR-82-0069   F/G 5/8   NL

END

FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(1)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFOSR-TR- 82-0845	2. GOVT ACCESSION NO. A120402	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Attention Control in Complex Information Processing Tasks		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Daniel Gopher, Gabriel Spitz		8. CONTRACT OR GRANT NUMBER(s) AFOSR-82-0069
9. PERFORMING ORGANIZATION NAME AND ADDRESS Technion-Israel Institute of Technology, Haifa, Israel		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F 2313/A2
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Office of Scientific Research/NL Bolling Air Force Base, DC 20332		12. REPORT DATE July 1982
		13. NUMBER OF PAGES 24
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

DTIC ELECTE OCT 1 4 1982 S D B

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Attention control; POC; selective attention; dual-task performance; secondary task; workload; time-sharing; training

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Results of this research can be summarized by stating that, under normal conditions, human operators are able to actively control their resource allocation. However, in the absence of feedback and proper instruction, the strategies which operators develop are often suboptimal. Moreover, time-sharing performance appears to be quite rigid and lacks the flexibility to respond efficiently to fluctuations in the requirements of the situation.

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

82 10 12 139

ACKNOWLEDGEMENT

The research presented in this report was supported by the Life Sciences Program, Air Force Office of Scientific Research, under Grant No. AFOSR-82-0069. Dr. Genevieve Haddad in the Life Sciences Directorate and Major Christopher Lind in AFOSR European Office were the scientific monitors of this grant.

AFOSR-TR- 82-0845

1

ATTENTION CONTROL IN COMPLEX INFORMATION PROCESSING TASKS

Daniel Gopher

Gabriel Spitz

Prepared for the Life Sciences Directorate

of the United States Air Force Office of Scientific Research

and European Office of Aerospace Research and Development

HEIS-82-7

Technion - Israel Institute of Technology

Faculty of Industrial Engineering and Management

Research Center for Work Safety and Human Engineering

July, 1982

Attention Control in Complex Information Processing Tasks[1]

Daniel Gopher

Gabriel Spitz

Technion - Israel Institute of Technology

Abstract

An important concern in human factors engineering of computer supported systems are the information processing capabilities of human operators. In the present paper we discuss major issues and review results of a series of studies conducted to investigate voluntary control of processing efforts under time-sharing conditions. It is shown that human operators can control and perform fine adjustments in their resource investments. Operators have more difficulties in lowering their standards of performance to release resources than improve performance when additional resources are made available. Voluntary control can be improved with proper training schedules, while practice without instruction may lead to sub-optimal resource utilization. The implications of these studies to the design of operator-machine interfaces are outlined.

Introduction

In the age of highly automated computer-based engineering systems, human factors specialists become increasingly involved in description and modeling of basic information processing and decision capabilities of the human operator. This emphasis is even more apparent when Management Information Systems (MIS) or Control Command and Communication Systems (C^3)

---

[1] The work reported in this article was supported by the Life Sciences Directorate of the Airforce Office of Scientific Research under grant. Dr. Genevieve Haddad at Life Sciences Directorate and Major Christopher Lind at the European Office were the scientific monitors of this grant.

are considered. Much of this work is related to the issue of workload, i.e. the attempt to adjust the number of tasks, formats of display, modes of response, rate of information exchange, complexity of procedures and difficulty of decisions to the attention capabilities of the human processing systems. The main emphasis in this work is on the measurement of the load imposed on the limited capacity control processes by different task configurations or environmental variables.

It is important to observe that such modeling efforts are essentially based upon a rather passive "bottom-up" conception of the human processor. Load is imposed by tasks, attention is required, processing resources are demanded. In contrast, recent models of attention emphasize the role of active "top-down" processes (Rabbit, 1979). The operator is conceived to be an active controler of his processing resources (Kahneman, 1973), he can allocate them in shares according to task emphasis (Navon and Gopher, 1979, 1980), and has considerable freedom in strategic planning (Rabbit, 1979). Limits of performance in complex tasks are described as joint outcome of the constraints imposed on the processing system by task characteristics and the amount of resources deployed to meet task demands.

An active rather than passive approach to the modeling of attention processes can revolutionize the design of human-computer dialogues. It is easy to show that the present designs of dialogues are dominated by the assumption that attention is indivisible and captured by tasks. One manifestation of this approach is the effort to simplify and limit the number of tasks or sources of information that appear simultaneously on the operator display. Another manifestation is the attempt to develop algorithms for sequential presentation of events which would present the operator with only a single event at a time and reduce the probability that attention will be distracted or captured by another task (e.g. Rouse, 1980).

If the operator has indeed good voluntary control on his resources, can allocate at will resources in various amounts and develop alternative strategies to the performance of the same tasks, the above approaches to the design of dialogues make suboptimal use of the operator's capabilities. It may impair considerably the pace of information exchange between the operator and the computer. This pace is one of the main bottlenecks in current computer supported systems.

In the present article we summarize and discuss results of several experiments designed to investigate voluntary control on processing resources under highly demanding time-sharing conditions. In all these studies subjects were given two tasks simultaneously and asked to perform them with different levels of task emphasis.

Experimental Paradigms

A typical dual task display for these experiments is illustrated in Figure 1 which is taken from Brickner and Gopher (1981). In this task subjects were asked to perform a letter typing and a digit classification task under dual-task conditions with 5 levels of intertask priorities. The letter typing task was performed by entering the correct code for a displayed letter with the left hand three-key keyboard. Digits were classified into two, predefined categories by the two keys of the right hand. Both tasks were self-paced and a new stimulus was immediately generated by the computer following a response to the previous one. However, if subjects did not respond within 3 seconds to the presented stimulus, a new stimulus was generated and the old one was recorded as a miss.

(Insert Figure 1 about here)

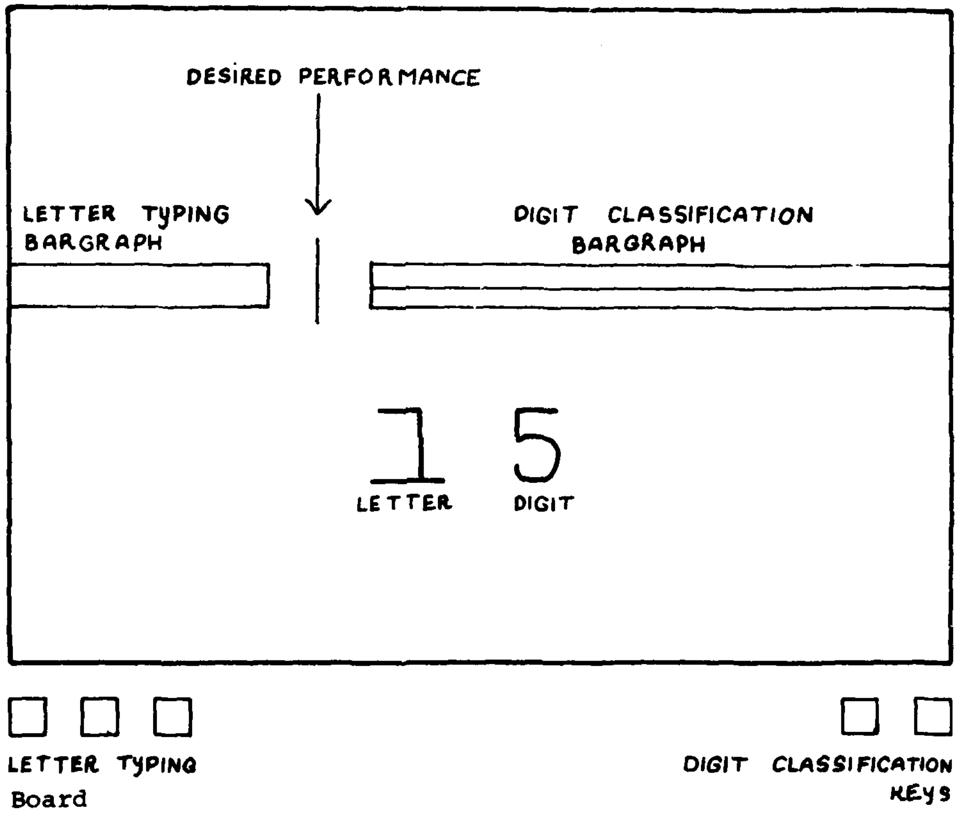


Fig. 1. Subjects display in the concurrent performance of tracking and letter typing with emphasis manipulation (from Brickner and Gopher, 1981).

In addition to digits and letters, the display also included a desired performance line which indicated the relative emphasis (priority) on each task in terms of levels of performance that have to be achieved. Also displayed were moving bargraphs that provided an on-line feedback to subjects on the difference between their actual and desired performance levels on each task. The height of the bargraphs at any moment represented a weighted average reaction time of a ten-trial running window.

Desired performance was determined in reference to a normalized baseline distribution of performance obtained for each subject in an earlier training session. Task priorities were manipulated by moving the desired performance line left or right from the center - equal priorities condition (which corresponded to the average of the baseline performance distribution on each task). A priority level of say .75 for letter typing corresponded to a level of performance that assumed the 75th percentile in the baseline distribution of typing performance for that subject. That is, an instruction to put a priority of .75 was actually a requirement to perform at a level better than the lowest 75 percent of the baseline performance levels. When performance demands on one task were increased they were simultaneously decreased on the other task and vice versa. (For example, on the digit classification task they were reduced to .25, or the 25th percentile on the baseline distribuiton of that individual.) Other priority levels were created in a similar way.

The same paradigm was employed to investigate time-sharing performance on a variety of task pairs. Gopher and North (1977), North and Gopher (1976), Wickens and Gopher (1977) investigated the joint performance of a one-dimensional compensatory tracking task and reaction time to visually presented digits. North (1977) used the same paradigm to compare all pair combinations of four tasks, compensatory tracking, reaction to digists, a running memory task and digit classification. Gopher and Navon (1980) conducted several experiments with a two-dimensional pursuit tracking task; Brickner and Gopher (1981) and Gopher, Brickner and Navon (1982) compared tracking and typing, Brickner and Gopher (1981) and Gopher and Arzi (in preparation) studied concurrent performance of letter-typing and digit classification. Navon, Gopher, Chillage and Spitz (in preparation) investigated joint performance of size matching and position tracking.

In the present article we attempt to present an integrative summary of the results obtained in these studies that are relevant to the issue of voluntary control on processing resources. We also present data from new experiments conducted to highlight some of the points in discussion.

Levels of Commitment

The first question to be examined is the potency of the priority manipulation as an experimental variable. A second question is the number of different emphasis conditions that can be created in concurrent performance by using the described experimental technique. A general answer to the first question is that in all our experiments the effects of priority changes were highly significant and in most studies this variable was the single most powerful variable in dual-task performance, as manifested in the percent of accounted variance.

As for the number of emphasis levels that can be created, in our early experiments we employed 3 levels of dual-task emphasis: high emphasis (.70), equal priorities (.5), and low emphasis (.3). Figure 2 is taken from Wickens and Gopher (1977). It depicts the effects of priority change on the joint performance of a single axis compensatory tracking and reaction time to visually presented digits which was a self-paced task. The fourth point on each curve (1.0) indicates single task performance levels. Note that tracking represents the continuous and dynamically changing task domain, while reaction time to digits was configurated as a discrete, choice and self-paced production task.

(Insert Figure 2 about here)

Similar effects of priority change were obtained when this manipulation was applied to a pair of discrete, externally paced, digit classification and letter typing task. Figure 3 is taken from Gopher and Arzi (in preparation) and illustrates the joint effects of priority change and difficulty manipulation of letter typing on concurrent performance of the two tasks (see Figure 1).

(Insert Figure 3 about here)

If we ignore for the time being the exact proporational value was aassigned to each priority level, a three level emphasis scale is not difficult to comprehend and communicate to subjects on an intuitive base. Moving from single task to dual task conditions, subjects may have an intuitive feeling of allocating about equal efforts to the performance of the two tasks. In the same manner, they may have a rough notion of unequal allocation, i.e. considering one task as primary and the other secondary. A three level emphasis scale is therefore easy to construct even on such intuitive base. But, are human operators capable of performing finer adjustments of their processing efforts?

In several more recent experiments we manipulated 5 emphasis levels in dual-task performance. These were presented as .25, .35, .5, .65

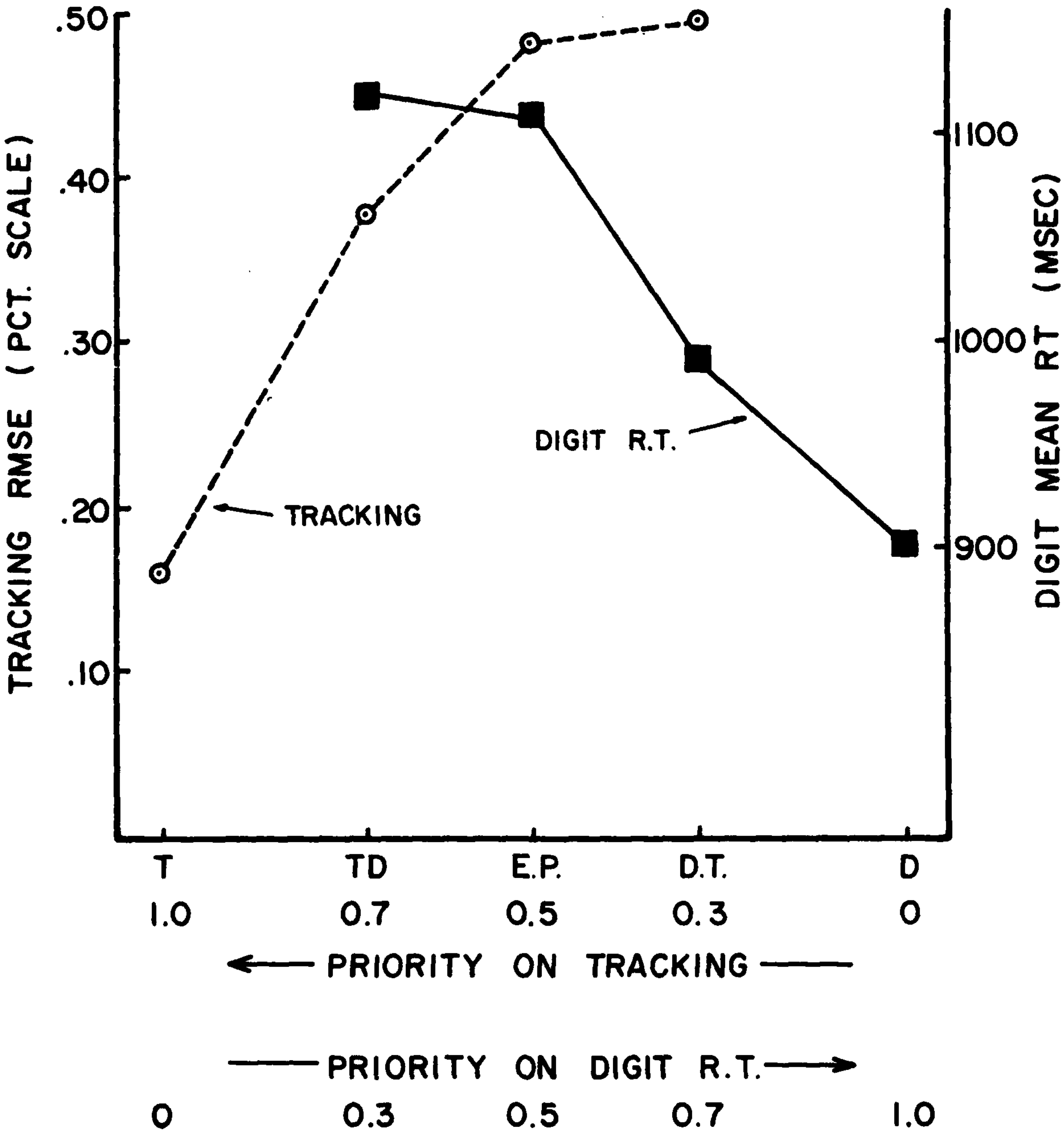


Fig. 2. Performance tradeoff between tracking and digit classification tasks as a function of task priorities (from Wickens and Gopher, 1977).

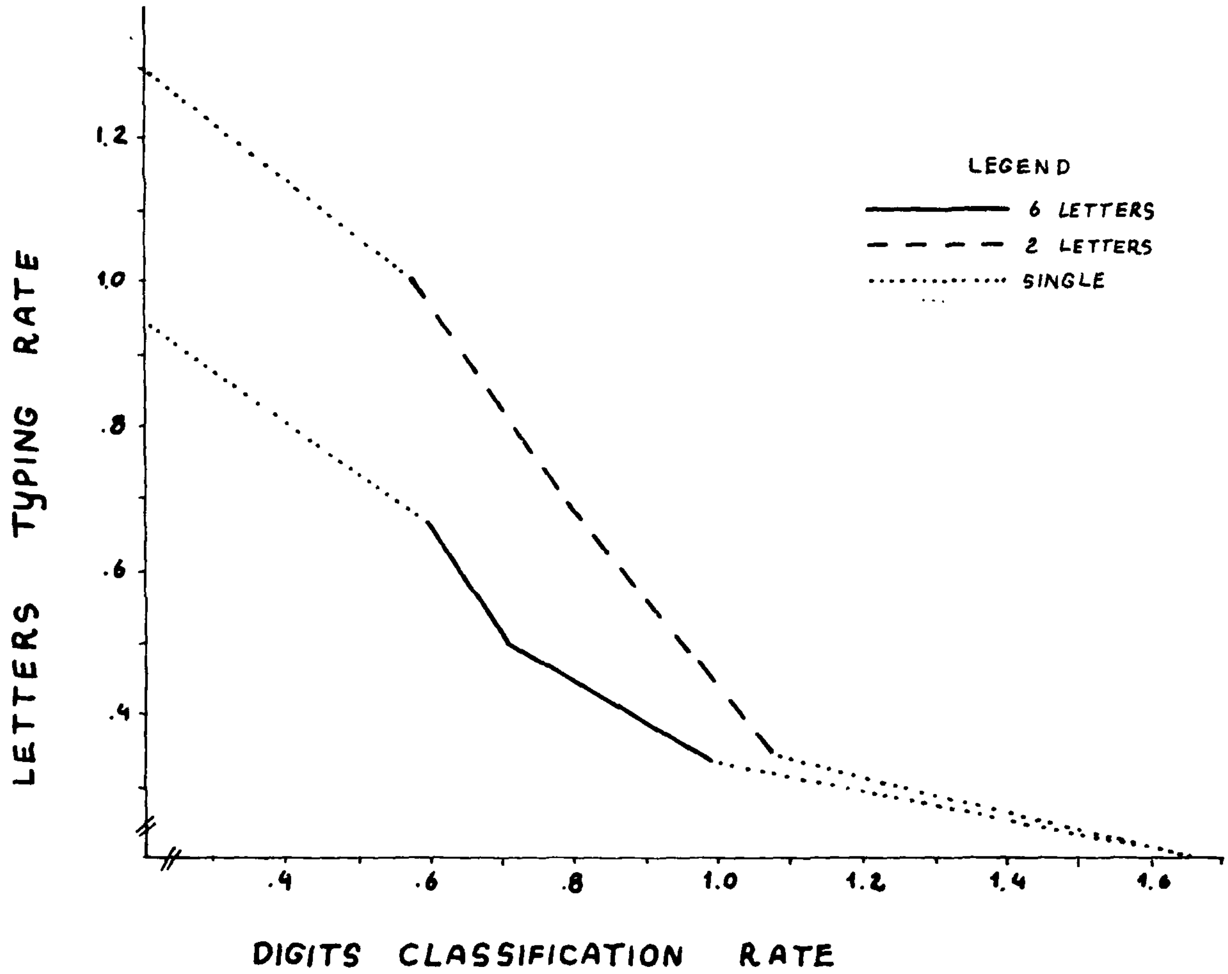


Fig. 3. Set size (difficulty) and priority effects on the joint performance of letter typing and digit classification tasks (from Gopher and Arazi, in preparation).

and .75 percentiles of maximum performance on each task or relative emphasis of .33, .54, 1, 1.86 and 3.0, respectively. Figure 4 is taken from the work of Gopher and Navon (1980) and depicts the tradeoff between vertical and horizontal tracking in pursuit tracking. Figure 5 is taken from Brickner and Gopher (1981) and presents the effect of priority manipulation on the concurrent performance of a two dimensional pursuit tracking and a letter typing task.

(Insert Figures 4 and 5 about here)

Gabriel Spitz, in his doctoral dissertation, has further refined the emphasis scale to include 7 levels of dual-task priorities (.10, .23, .35, .50, .65, .77, .90). Figures 6 and 7 depict the impact of this manipulation on the joint performance of the same pair of tracking and letter typing tasks that was used by Brickner and Gopher (Figure 5). Also plotted in this figure for comparison purposes are the results obtained for the 5 levels manipulation by Brickner and Gopher (1981).

(Insert Figures 6 and 7 about here)

It is evident from looking at these figures that subjects could adjust their time-sharing performance to the requirement to allocate their processing efforts in seven different amounts. This capability was similarly revealed in tracking and in letter typing performance. We can therefore conclude that human operators are quite capable of producing fine graded adjustments in the amount of resources committed to the performance of tasks under time-sharing conditions and that such adjustments have a strong impact on the efficiency of performance.

Another interesting question that emerges from the comparison between

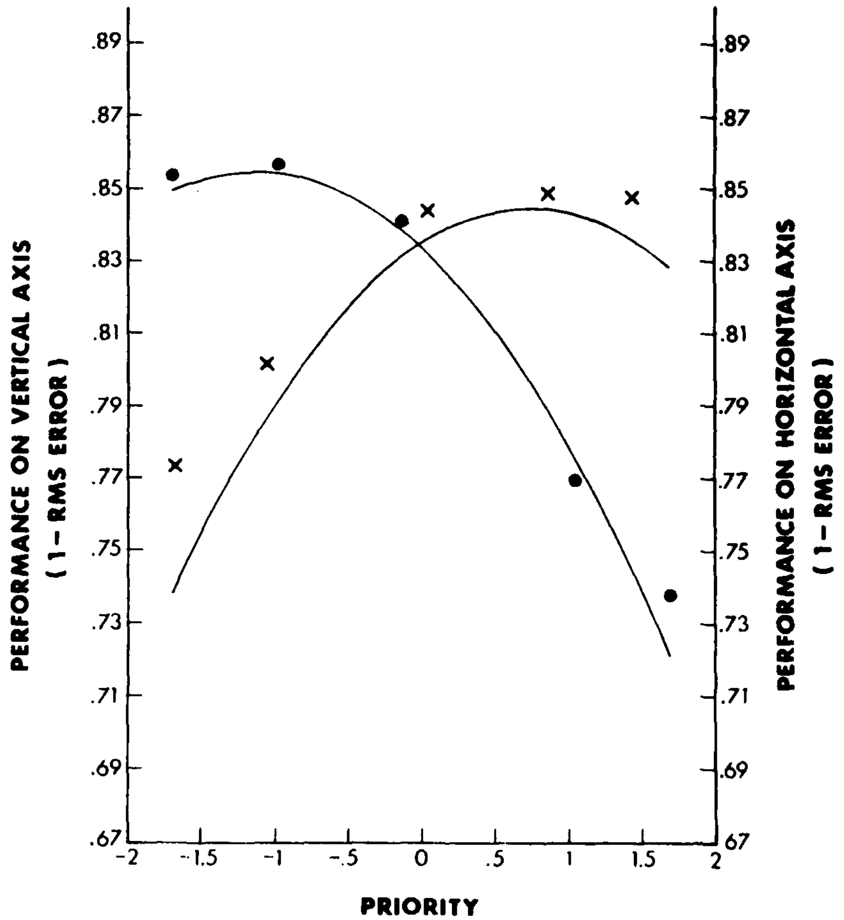


Fig. 4. Performance tradeoff between vertical and horizontal pursuit tracking tasks as a function of manipulating 5 levels of task priorities (from Gopher and Navon, 1980).

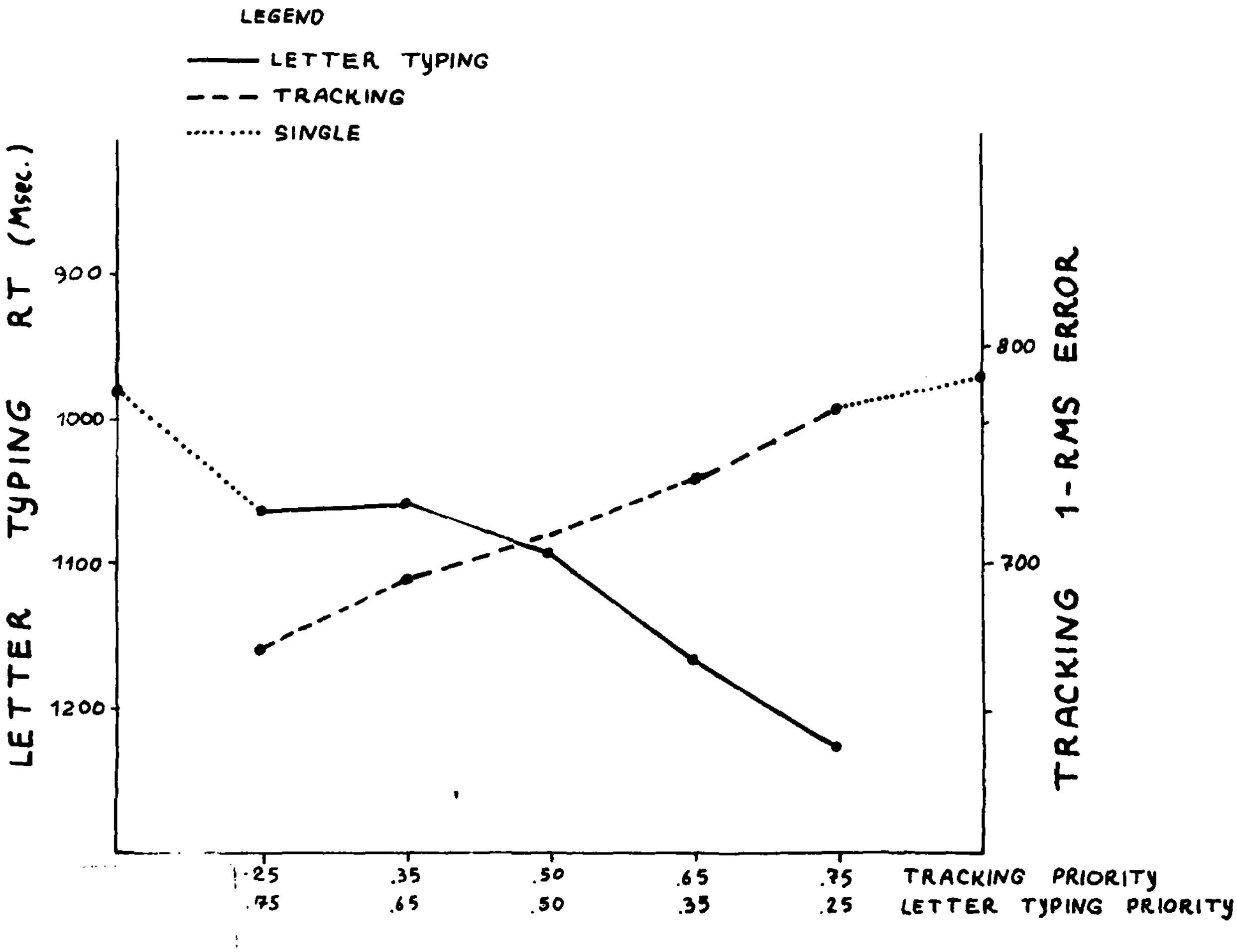


Fig. 5. Performance tradeoff between a two-dimensional tracking task and letter typing task as a function of task 5 levels of priorities (from Brickner and Gopher, 1981).

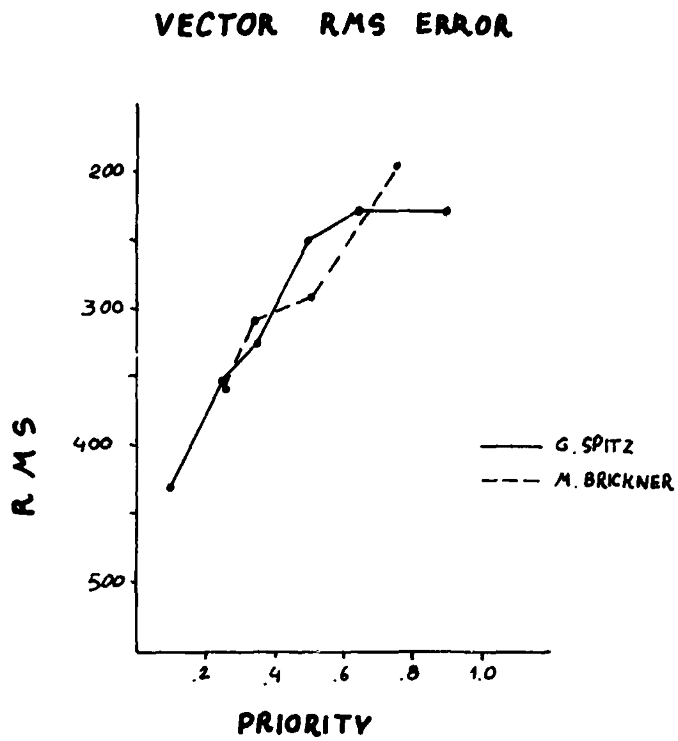


Fig. 6. Comparative effect of 7 and 5 levels of emphasis scales on the performance of two dimensional tracking task (from Spitz, in preparation, and Brickner and Gopher, 1981).

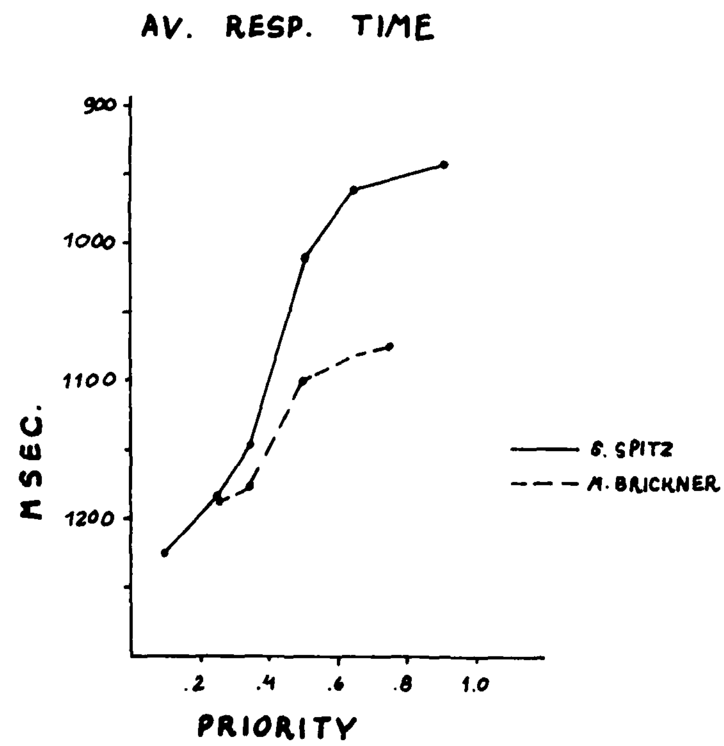


Fig. 7. Comparative effects of 7 and 5 levels emphasis scales on the performance of a letter typing task (from Spitz, in preparation, Brickner and Gopher, 1981).

the two sets of data presented in Figures 6 and 7 is the theoretical interpretation of levels of commitment. One possibility is that in every emphasis manipulation the operator exploits the full range of performance sensitive to resource investments and he is only concerned about the number of levels that should be created within this range. Another possibility is that he is also sensitive to the value assigned to each level and to the relative distance between levels. According to the first interpretation, any number of levels will cover the full performance range sensitive to resource allocation. Thus, the highest and lowest emphasis levels will always coincide with the edges of the resource sensitive region. When the number of emphasis levels is increased the same range is sliced into smaller units. The second interpretation proposes that the operator has a more objective sense of allocation which takes into consideration not only the number of levels but also their actual value.

The data plotted in Figures 6 and 7 tend to support the second interpretation. There is a clear difference between the function produced with a 5 and a 7 level scale. The seven level scale produced a larger range of performance tradeoff between tracking and letter typing and the distances between levels corresponded to their assigned percentiles in the reference baseline distribution which were different from those employed by Brickner and Gopher (1981).

Spitz in his doctoral dissertation set out to test this issue more directly. He varied both the range and the number of priority levels in a complete factorial design. His main findings are that subjects appear to be sensitive both to the range and number of required changes. These findings provide a strong support to the second interpretation demonstrating the impressive capability of human operators to control the allocation of their processing resources. Figure 8 is taken from one of Spitz' experiments and depicts the results obtained for three groups of subjects in the concurrent performance of tracking and typing. One group received 7 levels of priorities which span over a large performance range. The second received only three on the same range. The third group received 7 levels within a narrow performance range. The differences between groups are clear and show the effects of both variables.

(Insert Figure 8 about here)

Effects of Task Difficulty on the Resource Sensitive Range

How does task difficulty affect voluntary control on processing resources? We follow the definition of "task difficulty" proposed by Navon and Gopher (1979), which reserves this term for the description of the constraints imposed by task characteristics[2] on resource efficiency. According to this definition "task difficulty"is equivalent to the "average efficiency" to performance of a unit resources. Difficulty manipulations are those changes of task parameters that bring about changes in efficiency of processing resources. It follows that when difficulty increases and intertask priorities are manipulated, the range their effect on performance should decrease because performance can benefit less from an added unit of resources.

This prediction has been repeatedly supported in our dual task experiments in which both emphasis and difficulty were manipulated. For example, Gopher and Navon (1980) investigated performance tradeoffs due to emphasis change between vertical and horizontal pursuit tracking. When tracking difficulty was increased the rangeof tradeoff between axes as a result of emphasis change (5 levels) was reduced from 13 to 7 and to 3 percent tracking errors for the easy, medium and difficult versions,

---

[2] Navon and Gopher (1979) use the term subjects-task-parameters (STP) rather than task characteristics, to emphasize their view that these constraints include environmental conditions, response requirements, and permanent and transient characteristics of the performer.

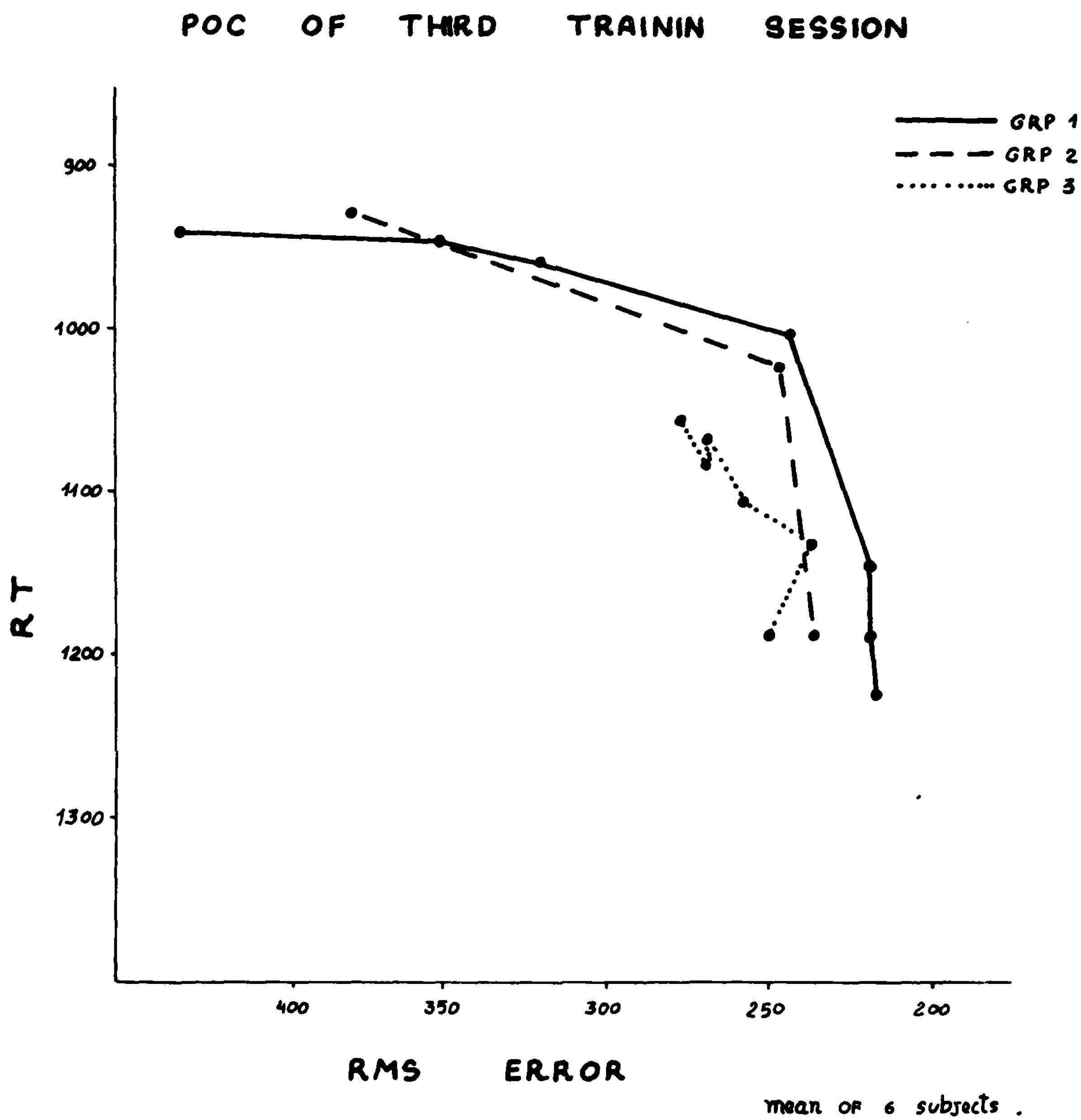


Fig. 8. The effect of number and range of priority levels on the concurrent performance of a letter typing and two dimensional size tracking task (from Spitz, in preparation).

respectively. In another experiment (Gopher and Arzi, in preparation), when an easy or a difficult letter typing task was paired with digit classification, the range of effects on typing rates of the priority manipulation (3 levels) was decreased from .37 to .27 letters per second on the easy and difficult versions, respectively (see also Figure 5). It is important to note that this decrease does not stem from a reduced capability to mobilize resources but simply reflects the fact that more resources are demanded to produce each unit of performance.

Minimal Control Levels

Manipulation of task emphasis under time sharing conditions is based upon the assumption that when priority of one task is increased subjects can recruit additional resources to improve performance on it by lowering their standard of performance on the other task, thereby releasing resources.

The ability of subjects to release resources by lowering their standards of performance is a central question to the study of attention control on which we know very little from previous research. Students of attention have almost exclusively dedicated their efforts to the exploration of the upper limits of the performance-resource function. That is, to identifying the level of performance beyond which further resource investment would not yield any performance improvement. The lower end of the function which represents the first level of commitment is very rarely considered (for one example see Norman and Bobrow, 1975). This lowest level determines the amount of resources required for minimal control, i.e. the first step that distinguishes between the state of "no control" and the state of "controlled response". The significance of this amount to the study of attention capabilities via dual-task interference is obvious; no matter what initial priorities of tasks have been instructed or voluntarily adopted by the performer, as long as he feels committed to perform both tasks, he is bound to invest on each one of them at least as much as the minimal level required for controlled response.

This commitment may be a prime contributor to the frequent observation that subjects fail to protect primary task performance when a secondary task is introduced, even if they are strictly urged to do so (Rolfe, 1971; Ogden, Levine and Eisner, 1979). Hence, upper performance levels on the primary task under dual task conditions may not be constrained by its own data limitation or resource efficiency, but by the ability of the operator to release resources from the performance of the time-shared task.

We first became aware of this issue when we studied the effects of increased task difficulty on the range of tradeoffs between vertical and horizontal tracking as a result of priority manipulation (Gopher and Navon, 1980). We found this expected decrease in top performance levels at high emphasis condition (.75) due to reduced efficiency of resources with increased difficulty. But, we also revealed a puzzling improvement in tracking accuracy at the lower emphasis level (.25) with difficulty increase. For example, vertical tracking accuracy (1-percent errors) on the highest emphasis condition was decreased from .860 to .849 under easy, medium and difficult tracking conditions, respectively. At the same time performance levels in the lowest priority conditions improved from .74 to .79 and .81, respectively. Thus, the region of performance tradeoffs as a result of priority change was shrinked from its two ends and not only from its upper end as would be predicted from the relationship between task performance and resource efficiency. In a closer examination of these results and additional self-testing in the performance of these tasks, we revealed that when task difficulty was increased it became increasingly difficult to lower the standard of performance (commit more errors) and release resources. That is, it was difficult to lower performance standards without losing control altogether. Minimal control levels demanded more resources on the difficult than on the easy task. But, why would the lowest levels of performance improve?

Before we attempt to answer this question let us consider the following example from bicycle riding. When riding a bicycle a certain amount of pedal forces are required to create the minimal movement velocity that would enable comfortable, stable, slow riding. If the bicycle is replaced by a tricycle, considerably smaller forces are now needed to initiate smooth, stable, riding, because the system is inherently more stable and easier to ride. At the same time the initial riding speed (performance) on the bicycle is likely to be much higher than on the tricycle. Hence, the first step of controlled performance on the more difficult task requires more resources but may also lead to a higher level of initial performance.

The relevance of this example to the findings of the tracking experiments is apparent. It also points out the possible existence of discontinuities of different magnitude in the performance resource function and in particular at its starting point. Such discontinuity reflects the resource demands of the first level of commitment, or the threshold level of resource investment as it was referred to by Norman and Bobrow (1975).

In a recent experiment conducted to investigate this issue we found that subjects had more problems in carrying out the instruction to lower their performance levels than to following the requirement to improve performance when the priority of a task was increased (Gopher and Spitz, in preparation). This outcome can be clearly observed in Figure 9 which is taken from this work. The figure depicts absolute deviations from desired performance levels only for the two lowest and two highest priority levels of a seven level emphasis scale which was employed in the study of vertical and horizontal tracking.

(Insert Figure 9 about here)

The magnitude of deviations is much larger on the two lowest priorities, which is a counter-intuitive finding,because one would regularly assume that under time-sharing conditions it will be harder to follow instructions to perform better than to perform worse. Analysis of the training data collected in this study together with a reanalysis of part of the data reported by Brickner and Gopher (1981) showed that in terms of attention control the main effect of training was to teach subjects to control their behavior at the low priority region. They learned to lower their minimal performance levels without losing control. Highly motivated but unpracticed subjects tend to lose control and lower their performance levels considerably more than requested. This phenomenon is illustrated in Figure 10 taken from Gopher and Spitz (in preparation), which presents horizontal tracking performance on the first and second days of training. It is apparent that on both days the largest deviations from the desired performance levels occur at low priority conditions, and that this is the main region of improvement during the second day of training.

(Insert Figure 10 about here)

The pattern of interaction between the variables of task difficulty and task emphasis may therefore be reversed as a result of training. Early in training larger decrements may be observed at low priorities on the more difficult task because control collapses. Later in training better performance can be observed in the same conditions on the more difficult task, because minimal control levels demand more resources but yield better performance.

To summarize, the range of performance tradeoffs between concurrently performed tasks which is under voluntary control, is constrained by the efficiency of resources and mandatory allocation to assure minimal control levels. Training may act to expand the range of performance senstitive to

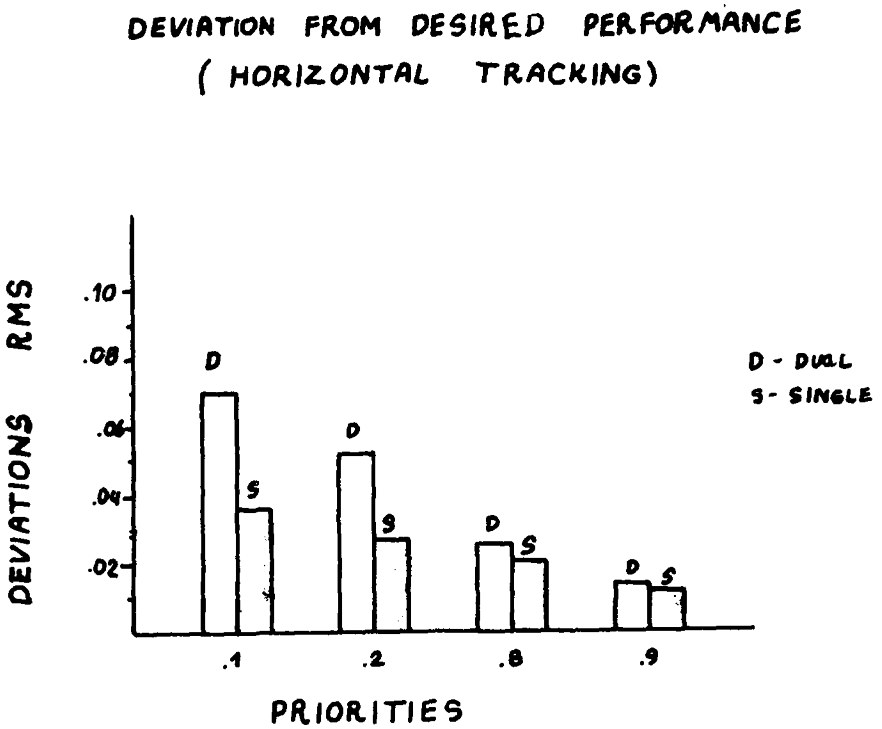


Fig. 9. Deviations of actual from desired performance on the two highest and two lowest priority levels of a seven level emphasis scale (from Gopher and Spitz, in preparation).

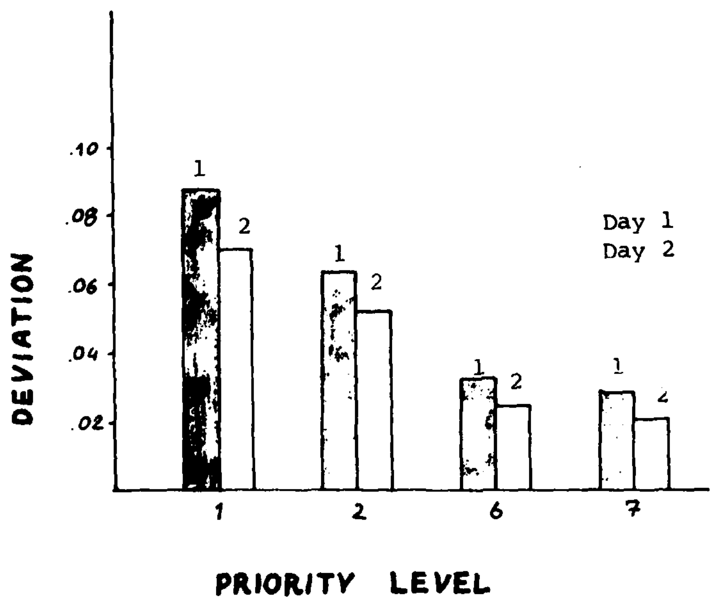


Fig. 10. Effects of practice on performance deviation from the desired level as a function of priorities (from Gopher and Spitz, in preparation).

strategic planning and voluntary control.

Training of Attention Control

We already discussed the effect of practice on the ability of operators to control their performance at low priority conditions. In the present section we examine the issue of training in a more general context.

Is voluntary control on processing resources a trainable skill? Can human operators be taught to better control their allocation of their resources under time-sharing conditions?

There is a wide data base that shows a very pronounced improvement in time-sharing performance as a result of practice (see, e.g., Gopher and North, 1977; Hirst, Spilke, Reaves, Cahacrack and Niesser, 1980). Nevertheless, the question still remains whether the human operator is a "natural optimizer". That is, assuming that concurrent performance calls for the development of an allocation strategy due to sharing of a common limited pool of resources, do operators make the best use of their resources?

This question was grossly overlooked in the general investigation of attention processes, and completely neglected in the study of complex performance skills (time-sharing being one of them). It was, however, implicitly postulated that the human is a natural optimizer, sensitive enough to detect deviations from optimal behavior; and would spontaneously acquire sufficient control on resource allocation to satisfy optimality.

An examination of the faculties attributed to the process of skill automation in the acquisition of psychomotor skills (Welford, 1976), or its cognitive counterpart, the transition from controlled to automatic modes of information processing (Schiffrin and Snyder, 1977) would show that automation is conjectured to represent the ultimate state of resource efficiency.

The only limiting condition is enough practice time. Issues of optimality, sensitivity and control are not even considered. Given enough time on the task, optimal behavior patterns would emerge spontaneously. Michael Brickner, in his doctoral dissertation, challenged these assumptions and set out to test the effects of different training schedules on attention control (Brickner and Gopher, 1981).

Brickner trained three groups of subjects for 10 hours in the concurrent performance of tracking and letter typing. The first group, which was labeled no priorities (NP) group, was given verbal instructions to put equal emphasis on both tasks. Subjects were given verbal feedback on their performance at the end of each two minute trial and monetary rewards for good performance. This manipulation represents the traditional approach. Subjects are allowed to develop their best spontaneous strategy. Performance is guided by verbal instructions, supported by verbal feedback and motivated by rewards.

Performance of the first group was contrasted with a second variable priorities group (VP), which was trained with on-line feedback indicators on their performance (as in Figure 1) and 5 different levels of task emphasis. A third group was added for control purposes. It received the on-line feedback indicators but was trained only in equal priority conditions (EP). This group equalled the first group in that priorities were not varied, and was equal to the second group in the existence of on-line augmented feedback on performance.

The results of training were rather dramatic. The group that was trained under variable priorities reached the highest levels of concurrent performance. These levels were achieved in spite of the additional interference and load which may have been caused by the requirement to monitor the feedback indicators, and adapt to changing emphasis conditions. A change of emphasis according to current models should hamper the development of automaticity. Figures 11 and 12 are taken from Brickner and Gopher (1981) and demonstrate the superiority of the variable priority group in both tracking and typing. The mere addition of on-line feedback indicators did not help typing and had only a limited impact on tracking performance.

(Insert Figures 11 and 12 about here)

Following training, subjects in all three groups were transferred to a new condition. In this condition the feedback indicators were removed in all groups and only verbal instructions were given. Subjects were required to maintain fixed performance levels on both tasks while their difficulty was manipulated. Difficulty was manipulated so that when it was increased on one task, it was simultaneously decreased on the other. To maintain fixed performance, subjects had to mobilize resources from the performance of one task to the other without the benefit of on-line feedback to inform them of the consequences of their efforts.

Figures 13 and 14 show that those subjects who were trained under variables priorities were much more successful in protecting performance. Performance of the other two groups simply reflects the change of task difficulty.

(Insert Figures 13 and 14 about here)

Similar results were found by Brickner in a second study in which letter typing and digit classification were paired.

From the results of these two experiments, we can conclude that those subjects that had to confront the requirement to change task emphasis developed a better voluntary control on their processing resources. This improved control enabled them to develop better allocation strategies in order to maximize the returns of their resource investment. They were also

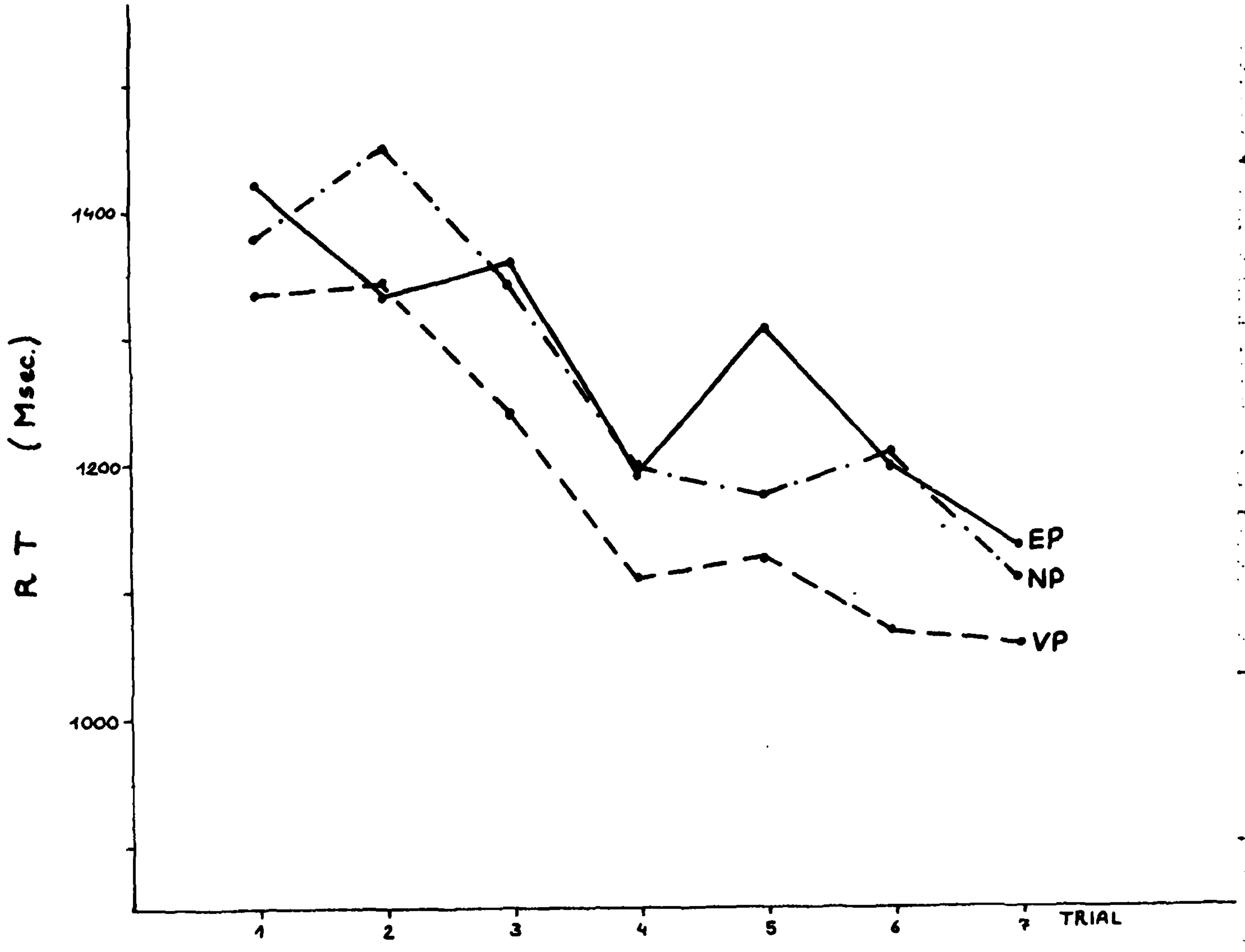


Fig. 11. Effects of training stragegy on letter typing performance during concurrent typing and tracking performance (from Brickner and Gopher, 1981).

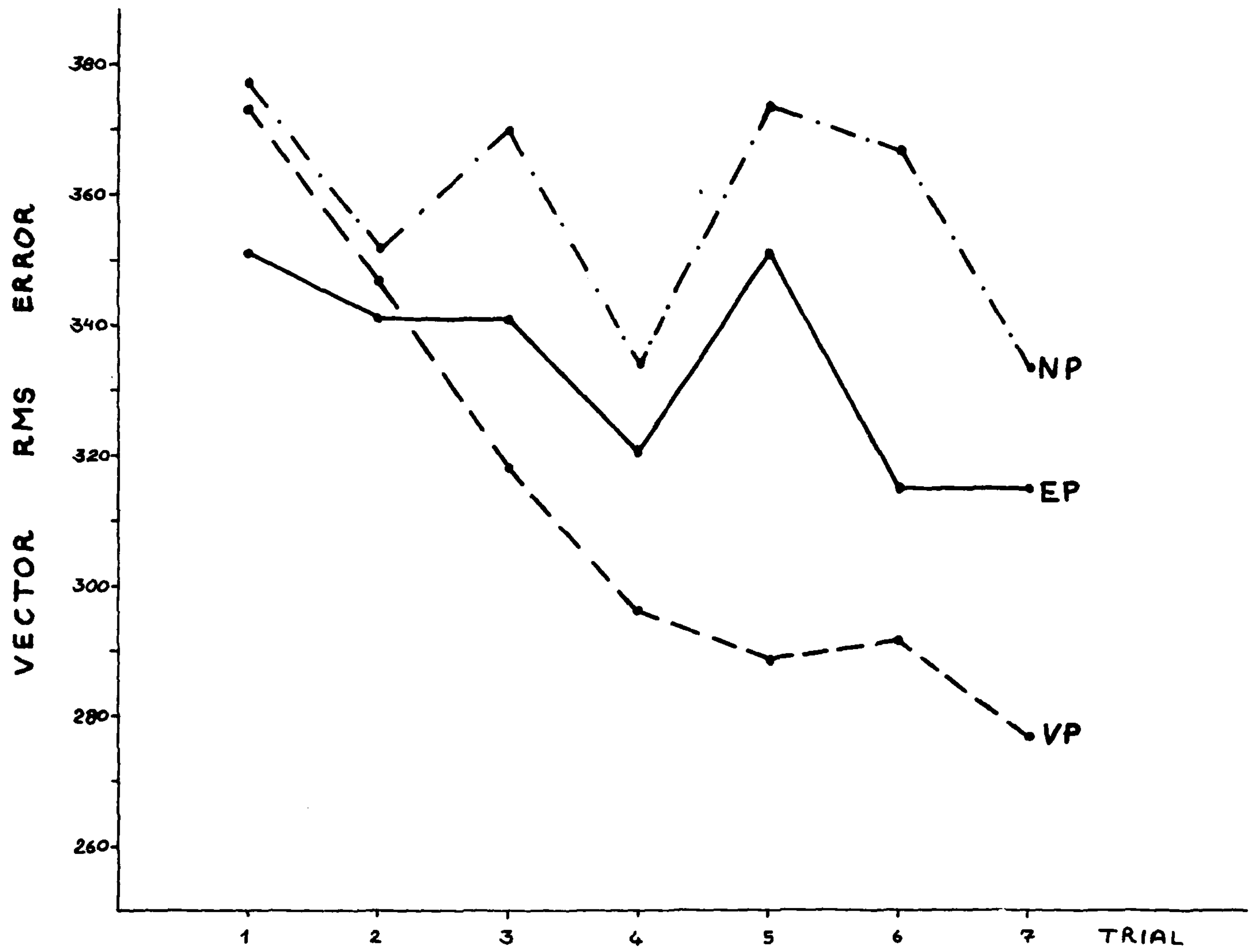


Fig. 12. Effects of training stragegy on tracking performance during concurrent typing and tracking performance (from Brickner and Gopher, 1981).

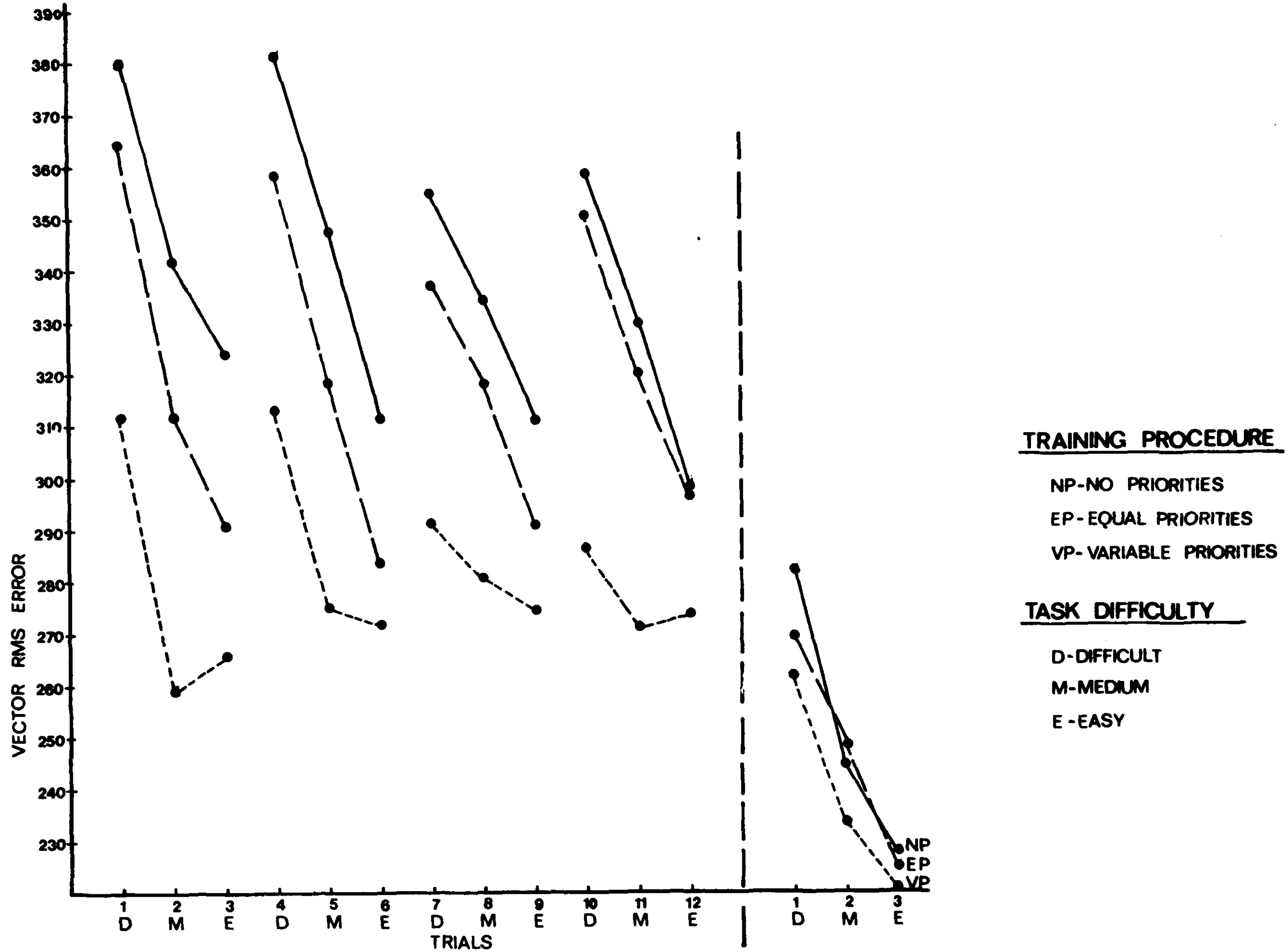


Fig. 14. Five replications of tracking performance in the three training groups under varying difficulty conditions (from Brickner and Gopher, 1981).

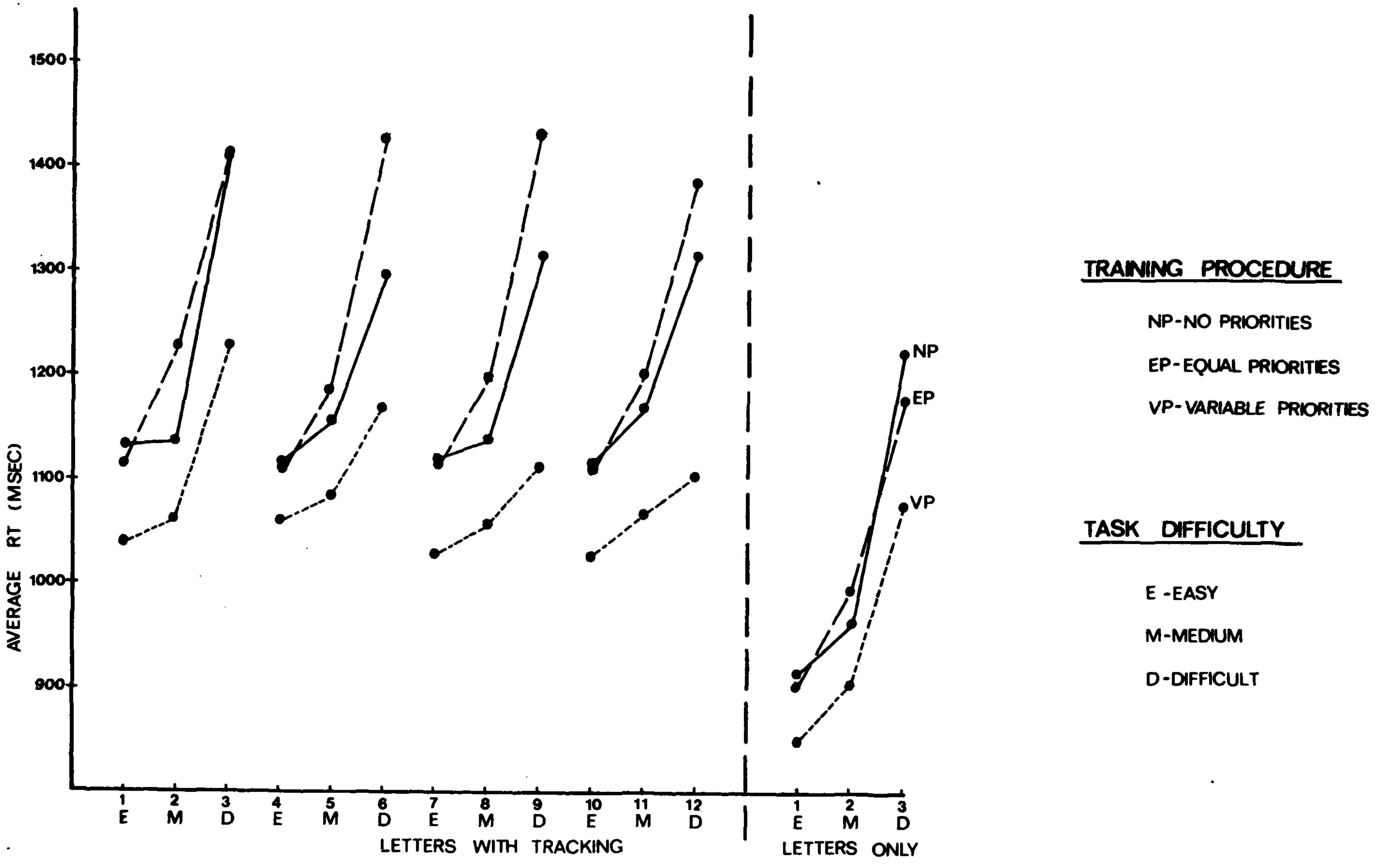


Fig. 13. Five replications of letter typing performance in the three training groups under varying difficulty conditions (from Brickner and Gopher, 1981).

more capable in flexible adjustment of their resource allocation to meet dynamic changes in task difficulty.

It appears that under regular circumstances human operators can actively control their resource allocation, but have only limited experience or knowledge to assure the efficiency and optimality of their allocation. In the absence of relevant information and proper instruction, spontaneous strategies may converge on suboptimal solutions. Furthermore, time-sharing performance appears to be quite rigid and lacks the flexibility to respond efficiently to fluctuations in the requirement of the situation.

Summary and Conclusions

We reviewed the main results of a series of studies conducted to investigate the nature and extent of voluntary control on processing resources. These results show that:

a) Human operators can actively control and perform fine adjustments in the allocation of their processing efforts under time-sharing conditions.

b) Operators are sensitive not only to the number of emphasis levels, but also to the distance between levels and the range of performance over which emphasis is changed.

c) As a result of a and b manipulation of task emphasis has strong influence on the tradeoff between tasks, and their level of performance under time-sharing conditions.

d) A major problem in attention control is the ability to lower performance standards and release resources.

e) A commitment to time-share the performance of tasks implies mandatory allocation of a certain amount of resources to each task to assure minimal control levels.

f) When the difficulty of tasks is increased the range of performance tradeoffs due to emphasis manipulation is reduced. This reduction is caused by the decreased efficiency of resources and the increased resource demands of minimal control levels.

g) Training improves control in low priority conditions and expands the range of performance amenable to strategic planning.

h) Training under variable priority conditions improves the ability of operators to use their resources efficiently and increase their ability to cope with changes in the demands of tasks.

Taken together these eight points provide an overwhelming evidence of the power, centrality and relevance of the attention control variable to the design of a wide variety of human-machine interfaces. It is astonishing that this dimension of human capabilities is completely missing in our present human engineering design books. It is true, as has been argued earlier in this article, that the human is assumed to be able to control his resources. However, this ability was overestimated on the one hand, because the human was assumed to be a natural optimizer. On the other hand, it was grossly underestimated, because we failed to recognize the full power of his ability to divide attention successfully on many levels.

The results presented in this article can lead to the development of better procedures to the design of operator-machine dialogues. These procedures should take advantage of the ability to perform tasks on several levels based upon their priority or processing requirements. Another area of application is the development of training schedules that will improve the ability of operators to cope with complex task demands.

Reference Notes

Gopher, D., Arzi, N. On memory resources and motor resources in typing and classification (in preparation).

Gopher, D., Spitz, G. Human ability to control the allocation of resources (in preparation).

Navon, D., Gopher, D., Chillag, N., Spitz, G. On separability of and interference between tracking dimensions in dual-axis tracking (submitted).

References

Brickner, M., Gopher, D. Improving time-sharing performance by enhancing voluntary control on processing resources. Technion - Israel Institute of Technology; Center for Work Safety and Human Engineering, HEIS-81-3, 1981.

Gopher, D., Brickner, M., Navon, D. Different difficulty manipulations interact differently with task emphasis: Evidence for multiple resources. Journal of Experimental Psychology: Human Perception and Performance, 1982, 8, 146-157.

Gopher, D., North, R.A. Manipulating the conditions of training in time-sharing performance. Human Factors, 1977, 19, 583-593.

Hirst, W., Spelke, E.S., Reaves, C.C., Caharack, G., Neisser, U. Dividing attention without alternation on automaticity. Journal of Experimental Psychology: General, 1980, 109, 98-117.

Kahneman, D. Attention & Effort, Englewood, N.J. Prentice Hall, 1973.

Navon, D., Gopher, D. On the economy of the human processing system. Psychological Review, 1979, 5, 189-253.

Navon, D., Gopher, D. Task difficulty resources and dual task performance. In: R.S. Nickerson (Ed.) Attention and Performance VIII. Hillsdale N.J. Erlbaum, 1980.

Norman, D.A., Babrow, D.J. On data limited and resource limited processes. Cognitive Psychology, 1975, 7, 44-64.

North, R.A. Task components and demands as factors in dual-task performance. University of Illinois at Urbana-Champaign. Aviation Research Laboratory, TR ARL-77-L/AFOSR-77-2, 1977.

North, R.A., Gopher, D. Measures of attention as predictors of flight performance. Human Factors, 1976, 18, 1-14.

Ogden, G.D., Levine, J.M., Eisner, E.J. Measurement of workload by secondary tasks. Human Factors, 1979, 5, 529-548.

Rabbit, P.A. Data driven and resource driven models of human information processing. In: Hamilton V. Warburton D.M. (Eds.) Human Stress and Cognition, Chichester, Wiley, 1979.

Rolfe, J.M. The secondary task as a measure of mental load. In: W.T. Singleton, K.A. Easterly & D.E. Whitfield (Eds.): Measurement of Man at Work, London: Taylor & Francis, 1971.

Rouse, W.B. Systems Engineering Models of Human-Machine Interaction. N.V. Elsevier, North Holland, 1980.

Shiffrin, R.M., Schneider, W. Controlled and automatic human information processing II: Perceptual learning, automatic attending and a general theory. Psychological Review, 1977, 84,127-190.

Welford, A.T. Skilled Performance: Perceptual and Motor Skills. Scott, Foresman, 1976.

Wickens, D.C., Gopher, D. Control theory measures of tracking as indices of attention allocation strategies. Human Factors, 1977, 19, 349-365.

Figure Captions

Fig. 1. Subjects display in the concurrent performance of tracking and letter typing with emphasis manipulation (from Brickner and Gopher, 1981).

Fig. 2. Performance tradeoff between tracking and digit classification tasks as a function of task priorities (from Wickens and Gopher, 1977).

Fig. 3. Set size (difficulty) and priority effects on the joint performance of letter typing and digit classification tasks (from Gopher and Arazi, in preparation).

Fig. 4. Performance tradeoff between vertical and horizontal pursuit tracking tasks as a function of manipulating 5 levels of task priorities (from Gopher and Navon, 1980).

Fig. 5. Performance tradeoff between a two-dimensional tracking task and letter typing task as a function of task 5 levels of priorities (from Brickner and Gopher, 1981).

Fig. 6. Comparative effect of 7 and 5 levels of emphasis scales on the performance of two dimensional tracking task (from Spitz, in preparation, and Bricner and Gopher, 1981).

Fig. 7. Comparative effects of 7 and 5 levels emphasis scales on the performance of a letter typing task (from Spitz, in preparation, Brickner and Gopher, 1981).

Fig. 8. The effect of number and range of priority levels on the concurrent performance of a letter typing and two dimensional size tracking task (from Spitz, in preparation).

Fig. 9. Deviations of actual from desired performance on the two highest and two lowest priority levels of a seven level emphasis scale (from Gopher and Spitz, in preparation).

Fig. 10. Effects of practice on performance deviation from the desired level as a function of priorities (from Gopher and Spitz, in preparation).

Fig. 11. Effects of training strategy on letter typing performance during concurrent typing and tracking performance (from Brickner and Gopher, 1981).

Fig. 12. Effects of training strategy on tracking performance during concurrent typing and tracking performance (from Brickner and Gopher, 1981).

Fig. 13. Five replications of letter typing performance in the three training groups under varying difficulty conditions (from Brickner and Gopher, 1981).

Fig. 14. Five replications of tracking performance in the three training groups under varying difficulty conditions (from Brickner and Gopher, 1981).